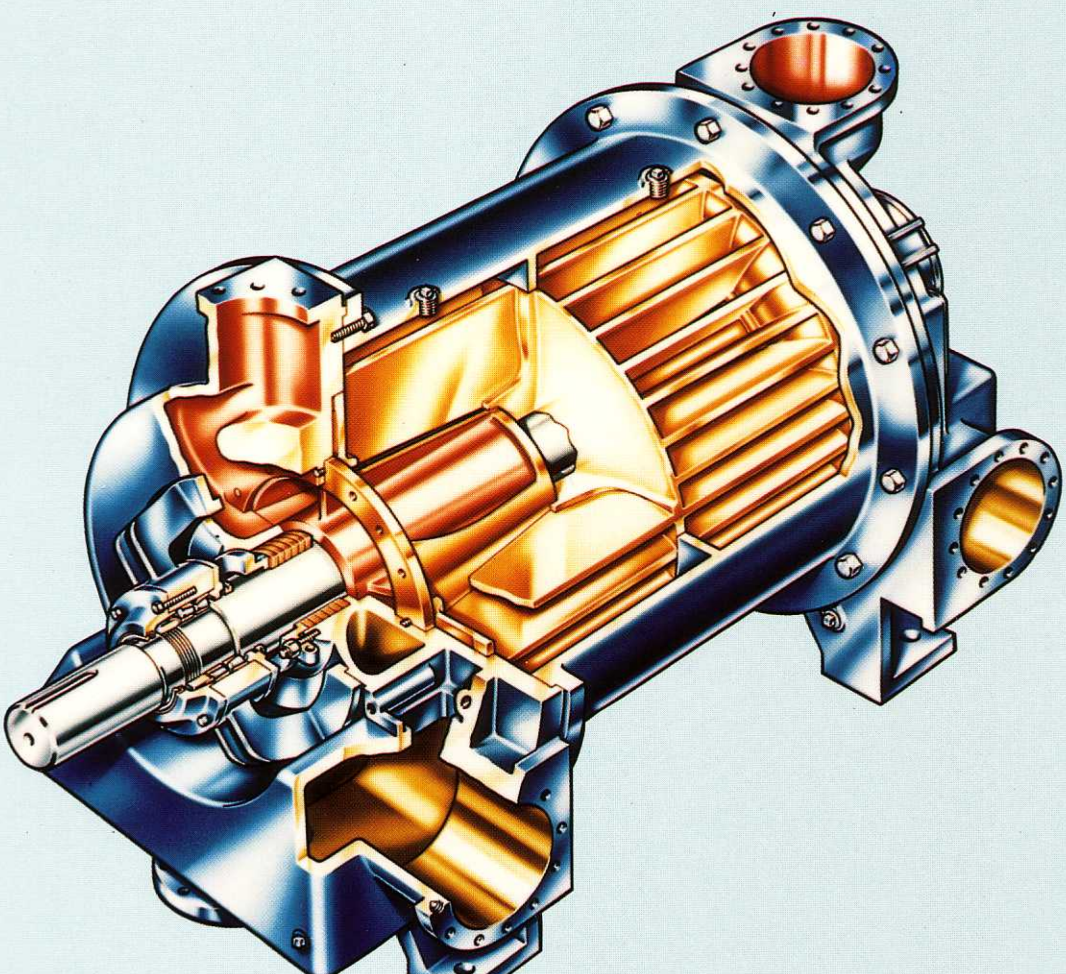
Good Practice

Guide 83

Energy Efficient Liquid Ring Vacuum Pump Installations in the Paper Industry



BEST PRACTICE PROGRAMME

Energy Efficiency Office

DEPARTMENT OF THE ENVIRONMENT

BEST PRACTICE PROGRAMME

ENERGY EFFICIENT LIQUID RING VACUUM PUMP INSTALLATIONS IN THE PAPER INDUSTRY

This booklet is No. 83 in the Good Practice Guide Series and is designed to offer guidance on ways of improving liquid ring vacuum pumps, both in existing plant and when planning new facilities, paying particular attention to energy management.

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* Front cover diagram is provided courtesy of Nash Engineering Ltd

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64. REDUCING ENERGY CONSUMPTION AND COSTS IN SMALL BAKERIES
65. ACHIEVING ENERGY EFFICIENCY IN THE MALTINGS INDUSTRY
66. ROTARY DRYING IN THE CHEMICAL INDUSTRY
67. ENERGY CHAMPIONS: A SELECTION OF CASE HISTORIES
68. ELECTRIC HOLDING OF HOT METAL IN IRON FOUNDRIES
69. INVESTMENT APPRAISAL FOR INDUSTRIAL ENERGY EFFICIENCY
70. ENERGY CONSERVATION IN THE DRY-CLEANING INDUSTRY
72. MONITORING AND TARGETING IN THE FABRIC CARE INDUSTRY
76. CONTINUOUS STEEL REHEATING FURNACES: SPECIFICATION, DESIGN AND EQUIPMENT
77. CONTINUOUS STEEL REHEATING FURNACES: OPERATION AND MAINTENANCE
78. ENERGY CONSERVATION IN LAUNDERING
84. MANAGING AND MOTIVATING STAFF TO SAVE ENERGY
85. ENERGY MANAGEMENT TRAINING
86. RUBBER MOULDING & CURING IN THE RUBBER PROCESSING INDUSTRY
87. THE PHARMACEUTICAL INDUSTRY
88. ENERGY EFFICIENT USE OF BOILERS USING CHAIN GRATE STOKERS
89. GUIDE TO COMPACT HEAT EXCHANGERS
90. ENERGY EFFICIENCY IN THE PROVISION AND USE OF INDUSTRIAL GASES
91. MONITORING AND TARGETING IN LARGE MANUFACTURING COMPANIES
92. REDUCING ELECTRICITY USE IN EXTRUSION-BLOW MOULDING OF THERMOPLASTICS
114. ENERGY EFFICIENT REFINING OF PAPERMAKING STOCK
115. AN ENVIRONMENTAL GUIDE TO SMALL-SCALE COMBINED HEAT AND POWER
116. ENVIRONMENTAL ASPECTS OF LARGE-SCALE COMBINED HEAT AND POWER
126. COMPRESSING AIR COSTS
127. ENERGY EFFICIENT ENVIRONMENTAL CONTROL IN THE GLASS INDUSTRY
128. MONITORING AND TARGETING IN THE CLAY BRICK INDUSTRY
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FOREWORD

This guide is part of a series produced by the Energy Efficiency Office under the Best Practice programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

- *energy consumption guides*: (blue) energy consumption data to enable users to establish their relative energy efficiency performance;
- *good practice guides and case studies*: (red) independent information on proven energy saving measures and techniques and what they are achieving;
- *new practice projects*: (green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;
- *future practice R&D support*: (purple) help to develop tomorrow's energy efficiency good practice measures.

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CONTENTS

ENERGY EFFICIENT LIQUID RING VACUUM PUMP INSTALLATIONS IN THE PAPER INDUSTRY

1. INTRODUCTION

The main uses of vacuum in a paper mill are to assist dewatering in the wire drainage and pressing sections:

- foil boxes require vacuum levels up to 7 kPa (27 inches water gauge ("WG)) centrifugal fans may be used;
- suction boxes have vacuum levels graded up to 40 kPa (12 inches mercury gauge ("Hg));
- rotary suction boxes used on heavier grades require up to 68 kPa (20 "Hg);
- suction couches (and Bagallay boxes) need up to 80 kPa (24 "Hg), with occasionally an initial lower vacuum box;
- pick-up, transfer and other press rolls require vacuum boxes operating up to 74 kPa (22 "Hg);
- felt cleaning and blow boxes to remove air between sheet and felt use vacuum up to 68 kPa (20 "Hg).

In addition to these main applications, there are a number of miscellaneous uses for vacuum such as stock de-aeration in headboxes on lower speed machines, for sheet transfer through the dryer section and in the steam and condensate system. Vacuum for these uses is generally provided from a local pump.

The main applications listed above are linked to a common system utilising liquid ring vacuum pumps in around 90% of cases: it is the efficient design of these systems which forms the subject of the Guide.

Vacuum pump systems account for a significant part of the total electrical energy requirements of a paper machine. A recent small survey carried out in the UK produced the figures in Table 1.

Table 1 Results of a small UK survey on vacuum power usage

Sector	No of machines	Average output tonne/hour	Total average power used kWh/tonne	% used by vacuum system
Fine paper	5	4.8	652	14.7
Boxboard	4	8.6	357	19.0
Multi-ply	3	15.3	355	15.8
Speciality	3	3.5	630	15.8

Individual figures showed a wide range of values, with the percentage of power used in the vacuum system ranging from 10 to 27%. The more modern machines generally used a higher proportion of energy in the vacuum system, indicating the growing significance of this function.

Another analysis of 15 recent machines world wide (newsprint, board, fine paper and tissue), yielded vacuum pump system power consumption figures ranging from 50 kWh/tonne for a linerboard machine, to 170 kWh/tonne for a fine paper machine. The average power consumption was 140 kWh/tonne compared with just over 80 kWh/tonne on the UK machines listed in Table 1. This is further evidence that power demand is increasing.

The reason for this lies partly in greater use of vacuum to produce more efficient wire dewatering, and partly to a trend to have lower web dryness from the press section (where it is more energy efficient to remove water compared with steam drying). The lower ex-press dryness is achieved by the greater effectiveness of press designs and more efficient felt cleaning, which in turn rely on higher levels of vacuum and air flow.

One important feature of the liquid ring pump is its relatively high usage of water for sealing. The 15 new machines previously referred to had water demands from 4,500 to over 14,000 litres per tonne of production. This operational aspect influences the overall energy usage of vacuum pump systems and will be dealt with separately.

The wide range of power consumption and water demand results in some cases from the trade-off between capital and running costs. Higher initial spending can substantially reduce operational energy and water demands, though this may not be a priority, especially for machines being erected through intermediaries in developing countries. Different machinery manufacturers also require very different vacuum supplies for their equipment - in any new installation it is important to look at the combined capital and running cost over a period of several years to determine the most economic course of action.

This Guide describes some ways to reduce energy and water demand in new and existing liquid ring vacuum pump systems.

2. OPERATION OF LIQUID RING VACUUM PUMPS

The principle of the liquid ring vacuum pump is shown in Fig 1. The pump has a positive displacement characteristic using liquid as a compressant. It operates by using a liquid ring (in this case water) as a piston to compress the saturated air pulled off the paper machine from a vacuum back to atmospheric pressure.

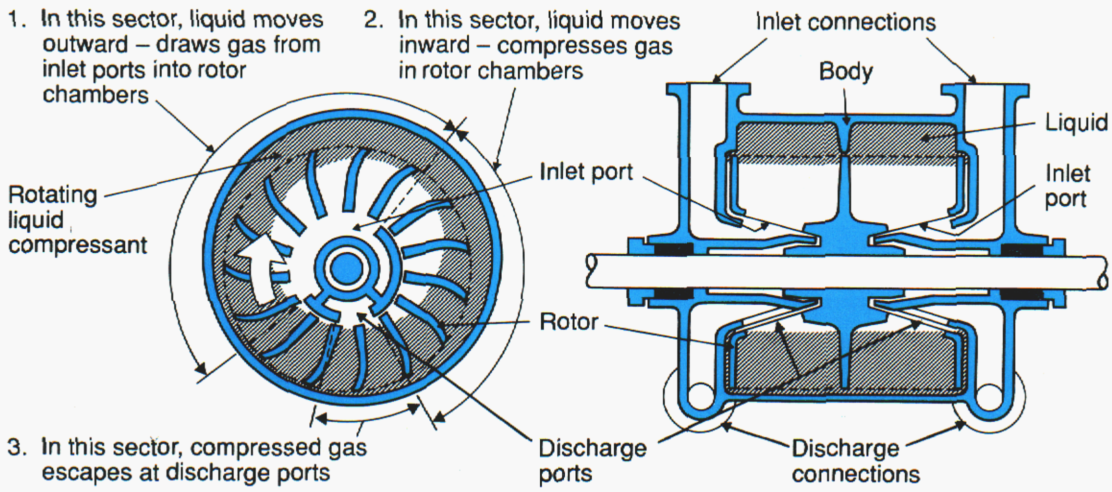

Fig 1 Liquid ring vacuum pump

The rotor keeps a ring of water rotating in the body of the pump. Water advances and recedes from the rotor chambers because the rotor axis is offset from the body axis. Some water flows out of the pump with the discharge air and the make-up water serves as a coolant, aiding pump efficiency.

The liquid ring vacuum pump is generally preferred to other types because its performance is particularly suitable to the demands of running a paper machine. The effect of changes in grammage, freeness and press felt condition, are to some degree self-compensating due to its constant volume, variable vacuum characteristic.

Fig 2 shows why this so. Curve A represents a typical relation between the vacuum applied to the paper web or a felt, and the resulting flow of air through it - the greater the vacuum applied, the higher is the air flow. As the liquid ring pump operates by drawing a constant volume (up to a limiting factor), the effect of greater resistance is simply to pull a higher vacuum, curve P. The intersection of the two curves defines the operational vacuum and air flow level achieved, in this case 300 mm Hg of vacuum and air flow of 80 m^3/min.

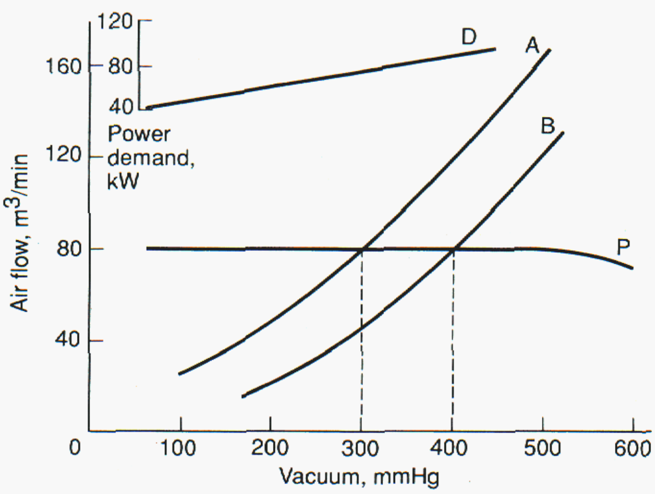

Fig 2 Relation between air flow, vacuum and power demand

If the resistance of the web or felt is higher, then curve A shifts to the right, becoming curve B. To achieve the same flow of air required by the pump, the vacuum increases to the higher value of 400 mm Hg.

This characteristic is beneficial if, for example, the greater resistance is caused by an increase of grammage and more water needs to be extracted from the sheet. This extra extraction will occur under the higher vacuum created. Similarly, if sheet freeness decreases, making it harder to draw out water, the vacuum will increase to compensate. A decrease in felt permeability, due either to compaction with age or increased water being extracted at the press nip, will also induce a greater vacuum.

This automatic response of a liquid ring pump to higher resistance is more efficient at removing water from the web than bleeding in air to keep the vacuum level constant. It does, however, affect power demand which increases to reflect the harder work being asked of the pump. Curve D illustrates the almost linear relationship between vacuum being pulled and the power required.

Generally the greater the operating vacuum the higher will be the power demand of a particular pump. Installing a larger vacuum pump operating at the bottom of its speed range usually makes sense because the power demand to achieve a designed air flow will be lower - one example of the need to relate capital to operating energy cost.

The design of liquid ring vacuum pumps has improved in recent years in response to the need to conserve energy. The Energy Efficiency Office New Practice Report NP/8 monitored the first installation of an improved pump design (the Nash 904 series) and compared it to earlier models. The energy saving is estimated to be around 27% compared with estimated consumptions for conventional designs.

Part of the inherent design improvement was the direction of part of the seal water supply to a spray injected into the suction of the pump. This has the effect of condensing a portion of the water vapour in the warm saturated air stream (reducing the total gas volume the pump has to handle), thus lowering the required pump capacity compared with an equivalent dry air capacity. It is possible to retrofit this feature to earlier designs. The benefit from this is dependent on the spray and seal water temperature - the lower the temperature the greater the pump efficiency - because condensation of the water vapour increases, further reducing the volume of air which has to be handled. This effect is becoming more important as paper machine stock temperatures are increasing and steam boxes are applied to the web.

Other features of new pump design are:

- lower water consumption;
- easier maintenance;
- reduced noise emissions.

3. SYSTEM DESIGN

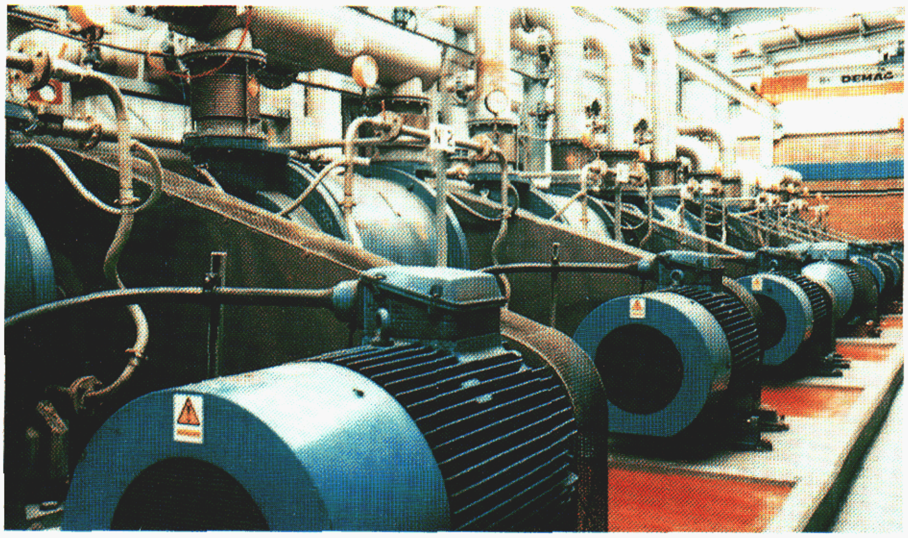

Fig 3 Mugiemoss Installation

The bank of vacuum pumps shown in Fig 3 have been recently installed on a board machine at Mugiemoss mill, the subject of Good Practice Case Study No 127. This illustrates a modern design placing vacuum pumps in a special building, allowing better water collection systems, better noise insulation and easier maintenance access.

Another feature of modern vacuum systems is that the pumps are arranged in a line, pulling vacuum from a common header separated into sections by valves, see Fig 4. The principal benefit derived from this arrangement is the ability to link the most suitable vacuum pump for the duty required. If, for example, a suction couch and pick-up box are linked to a single pump, problems occur during feeding up when the couch vacuum is lower than required because of the reduced resistance to air flow through the pick-up roll. A change can also occur during running in the couch vacuum as the pick-up felt condition alters. Suction boxes pulling on two separate felts which are linked together to the same vacuum pump can interact as the individual felts compact.

Further benefits derived from individual servicing of vacuum duty points are:

- the avoidance of energy wasting throttling valves;
- the ability to use $^1/_2$ or $1^1/_2$ vacuum pumps independently on a service which helps with standardisation of pump size;
- the provision of back-up by blanks in the header which may be removed to redistribute capacity in an emergency, or alternatively by installation of a secondary manifold (shown above the main header in Fig 4);
- the more accurate matching of capacity to duty minimises absorbed power.

Individual vacuum pumps are normally provided with separate motors geared or driven by V belts to suit the pump speed required. This allows the option to alter pump capacity by changing gear/pulley ratios and/or motor size.

An alternative to this is a lineshaft mechanically driven by a turbine using high pressure (16.6 bar) steam (see New Practice Report NP/8). In this arrangement low pressure (3.3 bar) steam exhausted from the turbine could then be used for process drying. The potential for using this technique depends on the particular steam and power balance in a mill, but in

the case detailed in NP/8, an installed capital cost of £256,000 (1986 prices) resulted in an annual energy cost saving - using steam compared with purchased electricity - of £131,400. This gives a payback of under two years. Drive belt breakages caused by sudden changes in individual vacuum pump drive load were initially a problem, but this was overcome and in over five years operation the turbine and gearbox have remained in excellent condition, with no trouble from the lineshaft and bearings.

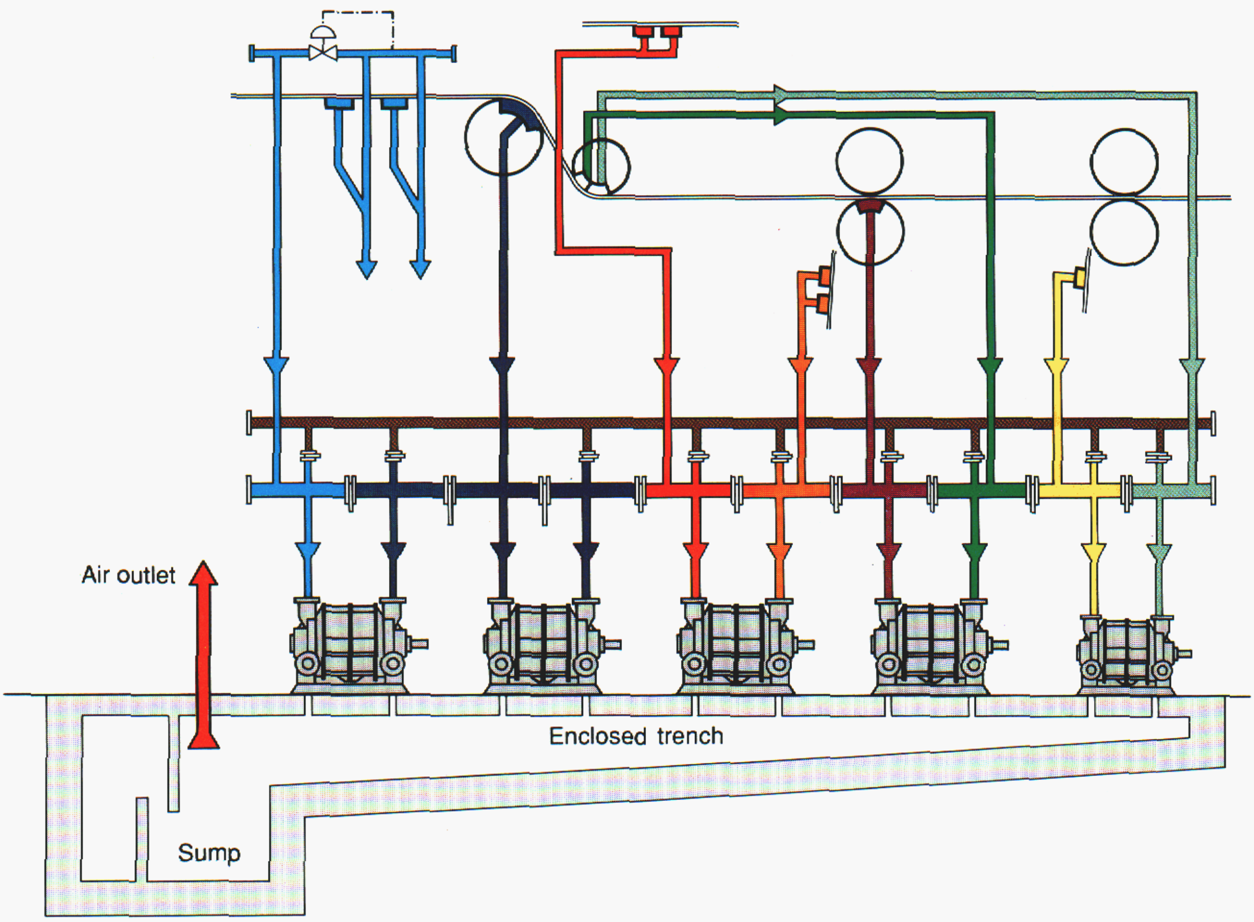

Fig 4 Typical arrangement of modern vacuum pump system

Separation of individual duties in a vacuum pump arrangement may be applied successfully when upgrading an existing system. A major problem with any system which has been running on a paper machine for many years, is that it was tailored to meet conditions which no longer apply. Different product may be made, fabric and felt design will have altered, even the basic configuration of the wire part and presses may have been changed. Consequently the vacuum system may well be no longer best suited to the demands being placed on it and the result will almost certainly be inefficient operation.

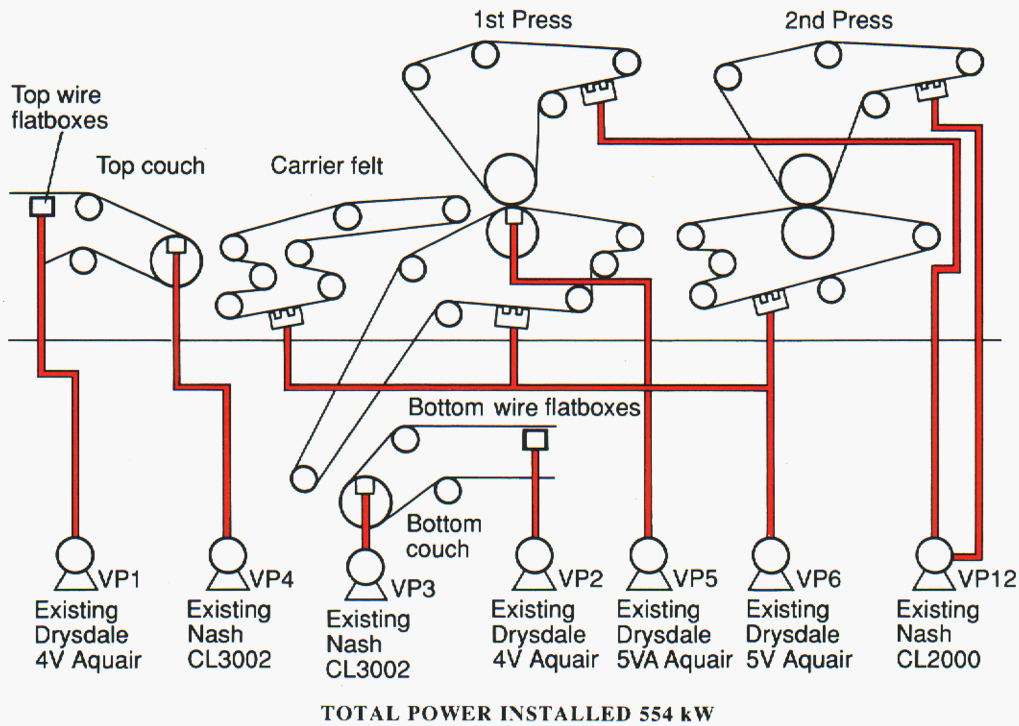

Fig 5 Existing Felt Cleaning Arrangement

A good example of the beneficial results of reviewing and upgrading the vacuum pump system is afforded by a project completed in 1992 on a coated board machine at Inveresk Carrongrove mill. The overall aim was to reduce the production losses because of breaks and broke from dirty press felts and to reduce the moisture content of the web entering the dryers, thereby allowing increased production.

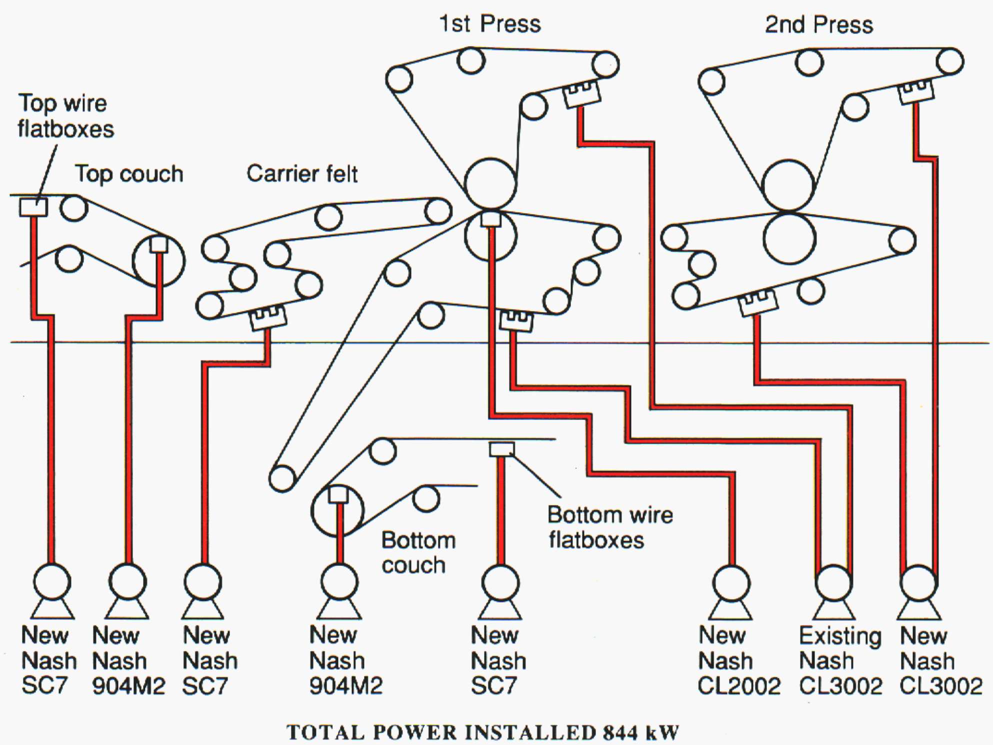

Fig 6 New Vacuum Pump Uprate Arrangement

The felt cleaning equipment was renewed by installing full-width oscillating showers and suction boxes in place of old undersized units. Additional vacuum pump capacity was installed. Most of the original pumps were replaced with new ones of more efficient design, and a proper header arrangement allowed the matching of individual duties to pumps.

Fig 7 Inveresk Carrongrove Mill Installation

The results of this work were as follows:

- reductions of about 2 per cent in sheet moisture entering the dryers have led to an average increase in output of 5 to 6% depending on grade;
- there appears to have been an overall drop in therms per tonne to run the machine despite an inevitable increase in vacuum pump power usage (it has not been possible to separate the effect of other changes);
- the machine now runs more smoothly.

Payback of the project is estimated at two years, even including the cost of a new 5.2 MW electricity supply to the mill.

4. WATER SYSTEMS

Liquid ring vacuum pumps need a high volume of water for condensing and sealing, originally fresh water was used for this, with the pump discharge simply being returned to the effluent plant. The cost of procuring and filtering fresh water has increased and this, together with greater environmental pressures, have lead to the need to reduce effluent.

A simple method of reducing water usage was to use vacuum pump discharge from the wire suction box and couch to feed coarse wire cleaning sprays which otherwise required their own supply of fresh water. As the vacuum pump water is warmed by passing through the pump, this also has the benefit of heating up the backwater system and improving drainage rate on the wire. The problem with this technique is that the vacuum pump discharge carries with it fibre drawn from the web which contaminates the sprays, making plugging a problem.

Discharge from the press vacuum pumps, especially those used for felt cleaning, is even more difficult to re-use because of the danger of contamination with felt fibres which, being generally synthetic, will disrupt the paper making process if they enter the stock system.

Carryover of fibre from the paper machine can be virtually eliminated by the installation of properly designed pre-separators on the vacuum services and a filter on the seal water circuit, allowing recovery and recirculation of vacuum pump discharge water. The only effect of the pump on the discharge water is a temperature rise from the heat of compression and the latent heat of condensation from the water vapour off the machine. The water may either be discharged without treatment, or can be reliably used for sprays and showers on the wire and for felt cleaning. Alternatively, the discharge water can be recirculated for re-use as sealing water without cooling.

When vacuum pump water is simply recirculated the overall temperature of the water system rises. Higher operating temperatures for liquid ring vacuum pumps affect their efficiency. As the temperature increases the same saturated air capacity can only be achieved by running the pumps faster with consequent additional power demand. Fig 8 illustrates the theoretical increase in power which would have to be applied through speed increase to achieve the same vacuum pump performance, as the seal water temperature increases.

Several degrees of recirculation closure are feasible, but the more completely closed the system the more likely it is that some form of additional water treatment may be required. Efficient pre-separation simplifies the degree of treatment.

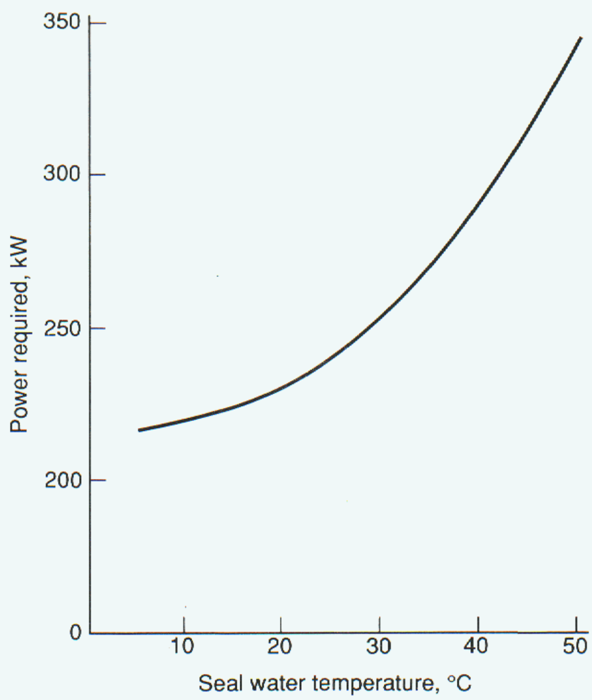

Fig 8 Theoretical power demand increase with increasing seal water temperature

Planned recirculation also needs the installation of a proper water collection system. It is simpler to control the operation if the pumps discharge into either a common culvert, or a manifolded discharge separator which may be divided into sections. There are a variety of ways to achieve this division, for example discharge water from the felt section may be kept separate from the rest of the machine. Design of the discharge system dimensions is important for noise attenuation and efficient separation.

5. RECIRCULATION SYSTEMS

One method of re-using vacuum pump sealing water is shown in Fig 9. Fresh water is fed only to the pumps providing higher vacuum for the couch, pick-up and presses. Water discharged from those pumps will be warmer than the incoming water and its re-use entails some sacrifice of vapour condensation, but it then goes to pumps with lower vacuum levels, such as wire suction boxes and felt conditioners, where vapour levels are lower.

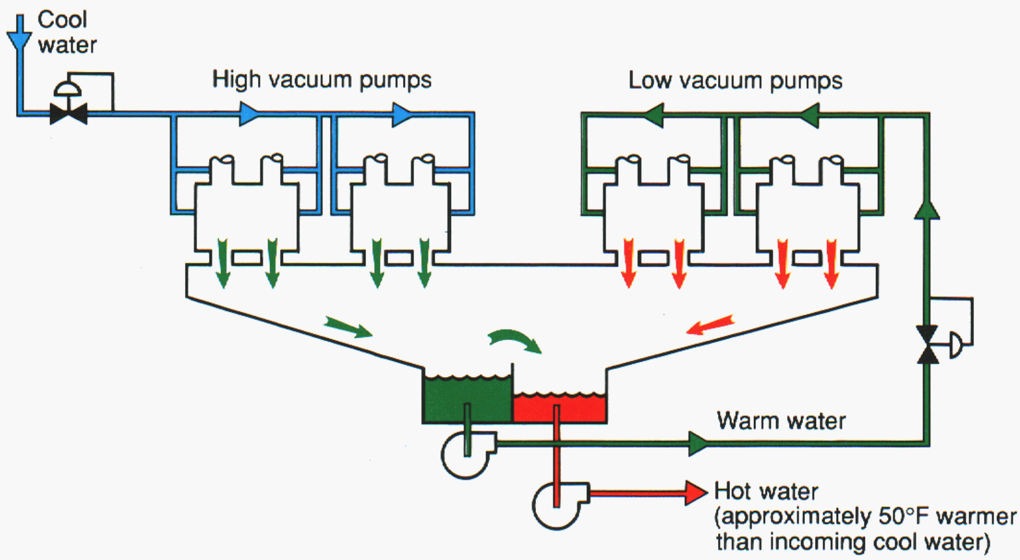

Fig 9 Cascade use of seal water

If pre-separation is installed, the hot water discharged from the second set of vacuum pumps may be used for sprays on the machine, or it may simply be discharged to effluent. This technique can effect a 50% saving in water use.

Temperature controlled recirculation of seal water (with pre-separation installed), also allows a reduction in fresh water usage while regulating the vacuum pump operation, see Fig 10. In winter the added water may be as little as 35% of the total being used, but this will increase in summer months when there may be no benefit.

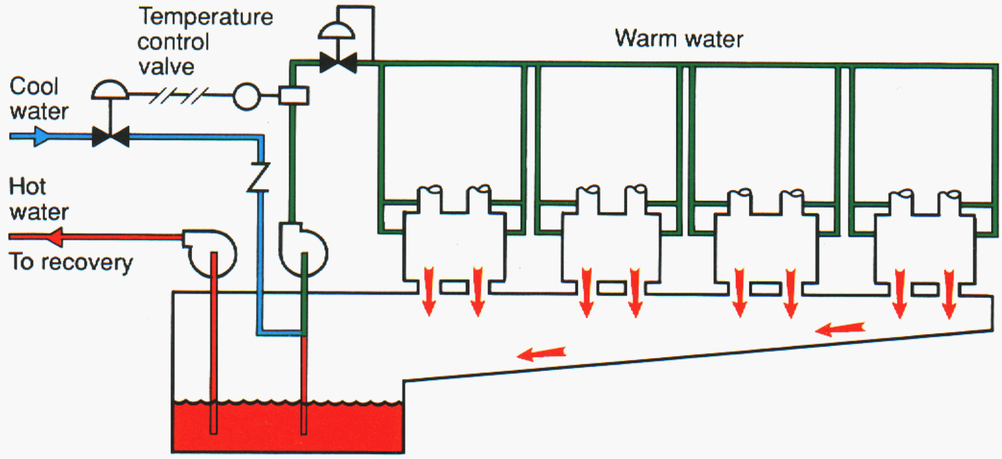

Fig 10 Temperature controlled recirculation

The disadvantage of this system is that there is no control of total water usage and it may be misused by raising the temperature control setting, taking the recirculation to very high levels at the expense of pump efficiency. A water saving of two thirds is claimed on a recent installation of this type by Tullis Russell.

The vacuum pump sealing water is directed to a collection tank (temperature controlled by water supplied from the filtration plant) and recycled to the vacuum pumps and felt showers. Overflow from the tank is taken back to the mill pond and filtration plant. Pre-separation is installed on most suction points.

This arrangement was adopted as part of a phased improvement to the vacuum system which also involved installing new felt conditioning equipment and increasing vacuum pump capacity. Benefits reported from the modifications are:

- improved cross machine profiles on the reverse and third presses;
- improved reel-up cross-machine profile;
- moisture content of the sheet entering the drying section reduced by 1.5%, leading to higher productivity.

A saving of some 30% of the total water used on the machine has been achieved. The payback purely in terms of water saving is five years, based on the costs of purifying the water, but this part of the project was undertaken with possible future environmental pressures in mind. If the overall project, including the improved felt conditioning, is considered, then estimated payback is between two and three years depending on sales of the additional output.

6. HEAT RECOVERY AND COOLING

Water recirculation systems may usefully be combined with improving overall energy efficiency. One simple and effective arrangement is to recover some of the heat generated in the recirculated water, thereby cooling the vacuum pump seal water and reducing the pump power required.

Fig 11 illustrates the system used on the board machine, the subject of Good Practice Case Study 127. Pre-separators are fitted in each vacuum line and the pump discharge is collected in a common exhaust pit. From there the seal water is fed to a duplicate set of spiral heat exchangers before being recirculated to the vacuum pumps with a controlled purging flow of around 5% (made up with fresh water) drawn off and added to the machine backwater system.

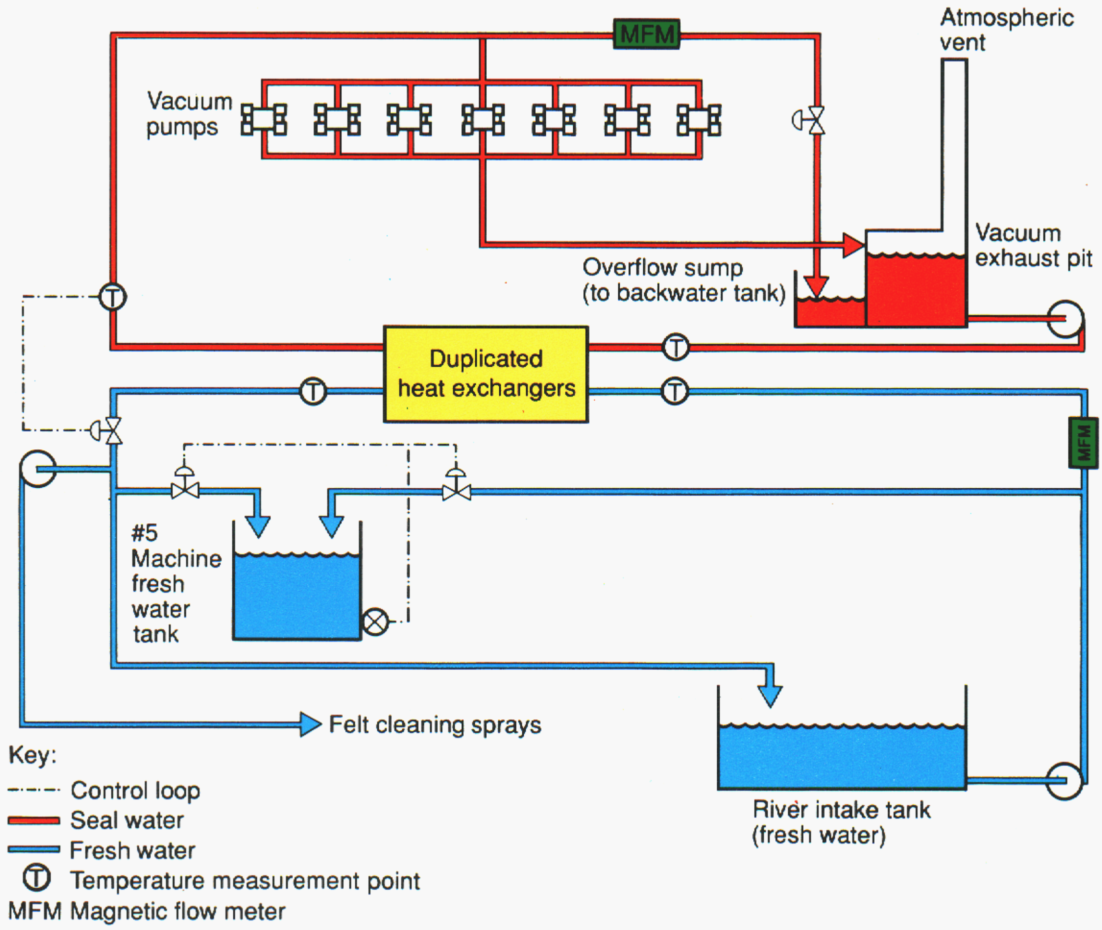

Fig 11 Seal water cooling system

The temperature of the seal water is controlled to a preset level of 30°C by varying the flow of fresh cold water passing through the heat exchangers. The warmed water is used preferentially in high pressure press felt cleaning sprays. The system has operated well for several years, though at times when the temperature of the incoming fresh water is as high as 20°C, it is not possible even at maximum flow rate through the heat exchangers to keep to the desired 30°C temperature for the seal water while maintaining the 5% purge level.

Some fouling of the heat exchangers by a soft, slimy, fibrous substance occurred initially, but this was easily removed with a pressure hose and is now controlled with biocides. If

allowed to build up and reduce the effectiveness of the heat exchangers, the increased seal water temperature affected the efficiency of the pumps causing the couch vacuum to drop.

The benefits of installing the heat exchangers are:

- a considerable reduction in fresh water (and effluent) flow;
- improved efficiency of the vacuum pumps;
- the energy saving from using the recovered heat for steam heating and the saving on drying steam because of the greater press efficiency.

It was estimated that the combined benefits yielded a payback period of 20 weeks in energy costs alone.

A different approach was selected by Caledonian for a new lightweight coated machine. In this case the paper machine is linked to a pulping plant and the overall availability of low grade heat made it more sensible to install a cooling tower for the vacuum pump sealing water.

The general operation of the system is shown in Fig 12. The seal water temperature is kept to around 25°C and make-up fresh water is only around 1% based on evaporative losses. A consequence of having such a closed system is that particular care must be taken to control the quality of the seal water to prevent corrosion, scaling and slime build up from bacterial growth. A detailed chemical treatment plan has been adopted using two different biocides, and biodegradable, low toxicity organic and inorganic corrosion and scale inhibitors. Six monthly sterilisation treatment is also carried out following Health and Safety guidelines.

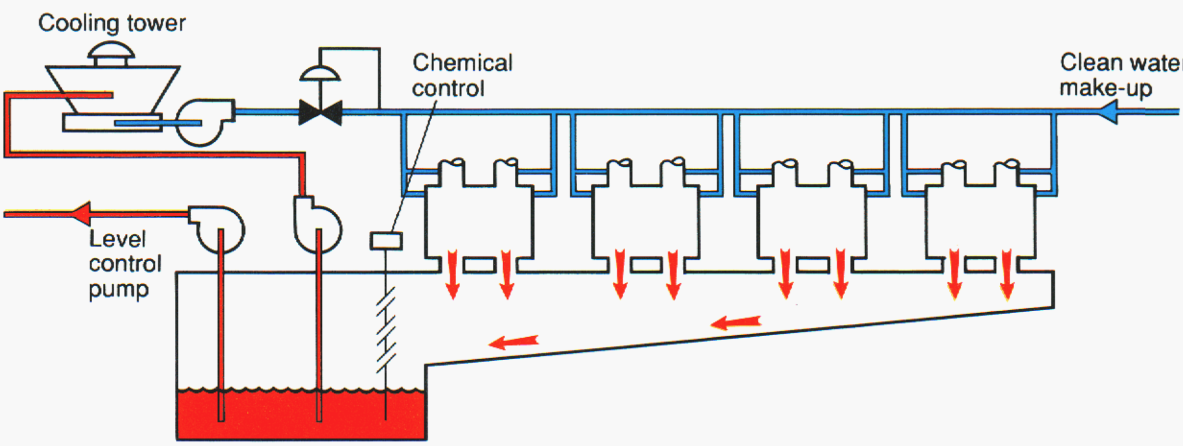

Fig 12 Recirculation of seal water through a cooling tower

The cost of this treatment is significant, but is preferable compared with the current high cost to Caledonian of using fresh water (36 p/m^3) for even a 5% regular purge of the system. A calculation comparing the additional water cost if a 'once through' arrangement were used is equally significant. In this case the extra cost, even when offset by the chemical costs, running costs of the cooling tower, and reduction in power demand by the vacuum pumps, still gives a payback on the cooling tower capital cost of less than a year.

A more relevant assessment of the benefit of the installation is to relate the additional power that would have to be applied to give increased vacuum pump speed if the cooling tower had not been installed. Compared with the normal operating temperature of 25°C, even if the temperature resulting from recirculation without cooling rose to only 35°C, the payback on installing the tower would be just 1.1 years; if the temperature were to stabilise at as high as 50°C the payback would be as little as 0.3 years.

7. INSPECTION AND MAINTENANCE

Sections 3 and 5 outlined the value of carrying out fairly extensive changes to a vacuum pump system. If energy and water requirements are to be kept to a minimum it is equally important that the vacuum system is properly maintained and that occasional reviews are carried out to monitor the performance and relate it to the design criteria.

Chemical treatment of vacuum pumps and associated piping using corrosion and scale inhibitors and biocides can control their internal condition but the effectiveness of this should be checked at intervals depending on the severity of likely contamination. Internal inspection of pumps and piping using fibre optics is an efficient way to monitor condition, especially if photographs are taken to provide a permanent record.

Pump efficiency may be assessed using a standard nozzle test which measures vacuum and air flow. Vacuum pump manufacturers have portable equipment available which can readily be linked on-site to a computer program to give figures comparing closely in accuracy to production test bed readings.

Vacuum pump system performance is frequently neglected because the equipment is sited away from the main paper machine and, with adequate maintenance, will pull a vacuum where it is required. With time, changes in operating conditions on the machine will alter demand on the system. Even when major alterations are made to the paper machine, wire part and presses, the effect on the vacuum system may be compromised to save capital.

Inefficiencies of the vacuum system usually exhibit themselves in higher moisture content of the web entering the dryers leading to costly increases in drying steam. This is not easy to measure, especially on machines with frequent grade changes, and may remain undetected. Other hidden effects are poor web moisture profile, which can increase broke, and ineffective clothing cleaning which reduces life and increases costs.

For these reasons it is useful to carry out a systematic review of the vacuum system to assess, in association with pump inspection and efficiency tests, whether the energy and water needs for the duties required can be economically improved. A list of features to examine (where it has been found that a modest investment will lead to paybacks below two years) follows:

- Sharing of duties may be compromising efficiency.
- Use of valves to control vacuum wastes energy and may cause instability.
- Effective felt conditioning requires that each felt position is independently served by a pump of appropriate capacity to suit the machine speed and felt design.
- Suction piping which is too small or restricted reduces vacuum and pre-separator drop-leg efficiency, giving higher power demand and increased likelihood of pump contamination.
- Badly designed pipework with vertical U bends and lifts will cause pulsing of water flow and vacuum fluctuations.
- Faulty pre-separator operation will give water carryover and unstable vacuum.
- Seal and condensing water flows and temperature, whether or not associated with a system of recirculation and temperature control, should be close to pump design characteristics.
- Applied vacuum capacity to all machine sections should be checked in the light of production and grade changes on the machine.

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